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WEIGHT REDUCTION OF AUTOMOBILE BY HIGH STRENGTH STEEL

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Abstract

Today, weight reduction is a very important design consideration for carmakers. High strength steel has become a very useful material for lightening the vehicle due to the reduced weight effect and cost. Therefore, high strength steel utilization averages 30 ~ 40% of the automobile weight. The class of 340 MPa to 590 MPa is a mainstream of this utilization-based concept on the body panel and performance. In the future, more strengthening is necessary to promote the weight reduction, however, on the other hand, the strengthening of steel deters the formability. Therefore, the application of a new material, which balances the strength and associated formability such as Dual Phase steel or TRIP steel, has recently been promoted. Honda and Japanese steel manufacturers have developed new TRIP steel. This paper outlines the recent Honda approach to reduce the car weight and its scheme of materials development based on a presentation made at an Arcelor symposium by Tanae et al. [1].

Introduction

The total number of automobiles currently used around the world for various purposes is estimated at approximately 840 million units. Under the circumstances, customer's desires and demands for functionality and performance continue to vary. To address such customer expectations, modern automobiles encompass more trims than before resulting in increased weight.

In addition, the traffic environment surrounding automobiles becomes increasingly difficult from year to year, causing social problems of serious concern, such as the growing incidence of traffic accidents. Safety regulations to combat these problems become more stringent each year. The increased presence of safety devices aboard automobiles designed to achieve legal compliance makes them heavier than ever. With the impact of air pollution caused by exhaust emissions seriously threatening the global environment, automobiles with a minimal environmental load are being sought. However, an increased number of heavier cars would also escalate the environmental load. Thus, present-day automobiles face a wide spectrum of challenges, which carmakers try to overcome by various methods. Among them, the process of reducing the car weight stands out as an approach to resolve these conflicting tasks and improve the driving performance.

Trends in Automotive Legal Compliance

Existing laws and regulations for road traffic are plentiful and diverse, ranging from traffic regulations to emissions control, fuel economies and collision safety. In addition, carmakers need to respond to demands from national insurance institutions. Anticipated trends in the implementation of regulations relating to emissions control, fuel economies and collision safety are listed in Table I and Figure 1.

Table I. Trend of emission and fuel economy regulations.

Country	Region	Regulation
EU		CO2 Agreement 140g/km to 2009 (120g/km to 2012)
USA	All	CAFÉ regulation reinforcement
	California	GHG 50% improvement of fuel economy (from 09 to 14 MY)
	Northeast Area	Adoption of California State's GHG
China		Lower limit regulation for fuel economy 1st step : from 2005 2nd step : from 2008
Korea		CAFÉ regulation (from 2010)
Japan		Re-regulation for fuel economy (from 2015)

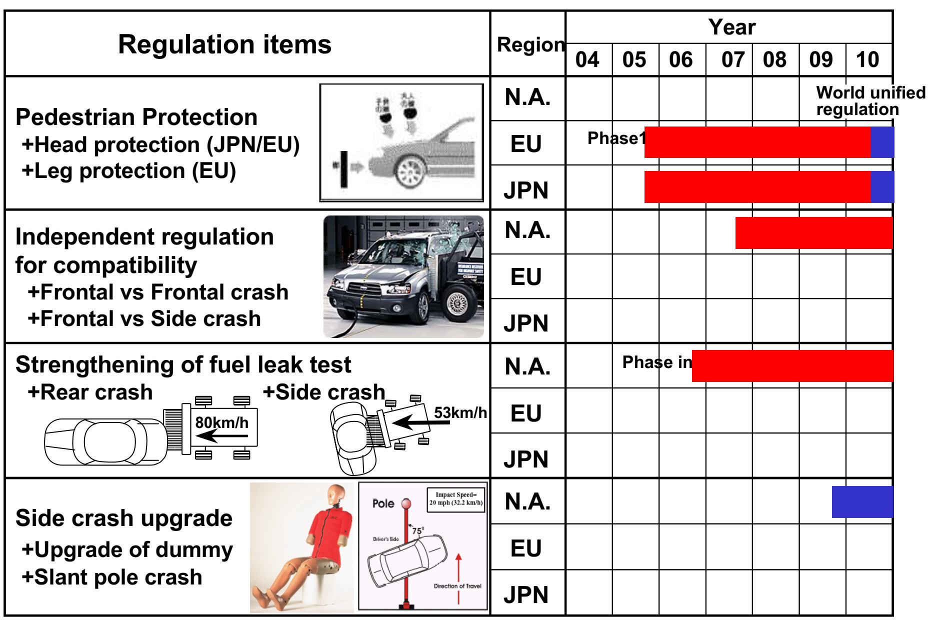


Figure 1. Trend of crash safety regulations.

Table I suggests that as fuel economy regulations become increasingly stringent, carmakers strive to improve the efficiencies of their internal combustion engines and modify their fuel recipes. One promising approach is reducing the car weight. According to estimates worked out by Egawa and others [2], reducing the car weight by 100 kg will improve the fuel economy by about 1.3 km/l.

A look at ongoing trends in the implementation of collision safety regulations (Figure 1) also reveals increasingly stringent regulations. For example, in North America, reactions to tighter legal and insurance demands as in the case of SUV collisions (side crash) and high-speed collisions (rear crash), call for the reinforcement of body frames and the addition of collision protection devices typified by SRS (Supplementary Rescue System), raising the car weight.

Although the requirement for lower automotive emission levels and higher fuel economies on the one hand side and that for collision safety on the other side are barely compatible demands at first sight, a compromise is possible by applying particular car weight reduction technologies.

Weight Reduction Methods

As explained earlier, while vehicle weight is increasing for various reasons, the need for weight reduction is also intensifying. This chapter intends to discuss how to reduce the weight of the body-in-white being the major structural element of a vehicle.

Individual carmakers pursue further reductions in the weight of their bodies-in-white through the implementation of structural designs evolving from their particular expertise and optimum choice of materials. The process of reducing the weight of the body-in-white through optimized material selection is approached in two ways:

1. Migrating to materials of lower density, i.e., replacing sheet steel, the present mainstream car body material, with a lower density, such as aluminum or plastics.
2. Using materials of higher strength allowing for a reduction in the gage of sheet steel.

Designers working for a carmaker optimally combine these methods to develop designs that also meet cost constraints. The migration to lower density materials involves a relatively large cost increase and is often used in manufacturing luxury and some specialty cars, such as sports cars. The widespread use of stronger materials, on the other hand, involves a relatively low cost increase to achieve a weight reduction and therefore, attracts attention for its potential application to a wider range of automobiles.

This paper presents the process of using high strength steel to make automobiles lighter as it continues to penetrate a rising number of auto carmakers.

Development of High-Strength Steel

Figure 2 shows the percentage ratios of individual materials used in the manufacturing of automobiles currently in production. The chart shows that steel accounts for about more than 60% of the total weight of an automobile. The body-in-white is built by stamped components of steel sheet and assembly, e.g., by spot-welding. The body-in-white of a typical Honda models weighs from 200 kg to 400 kg. The body-in-white weight is a key determinant of the performance characteristics of the automobile, such as its driving performance and collision safety. This means that building a lightweight and high performance body-in-white is vital to enhancing automotive performance.

The steel grades applicable for building Honda cars are specified by an in-house standard called the "Honda Engineering Standard" (HES). In recent years, however, the types of steel sheet defined in the HES alone have not fulfilled expectations in terms of making lighter bodies-in-white. To resolve this situation, Honda has developed a new variation of high-strength steel in cooperation with Japanese steel makers.

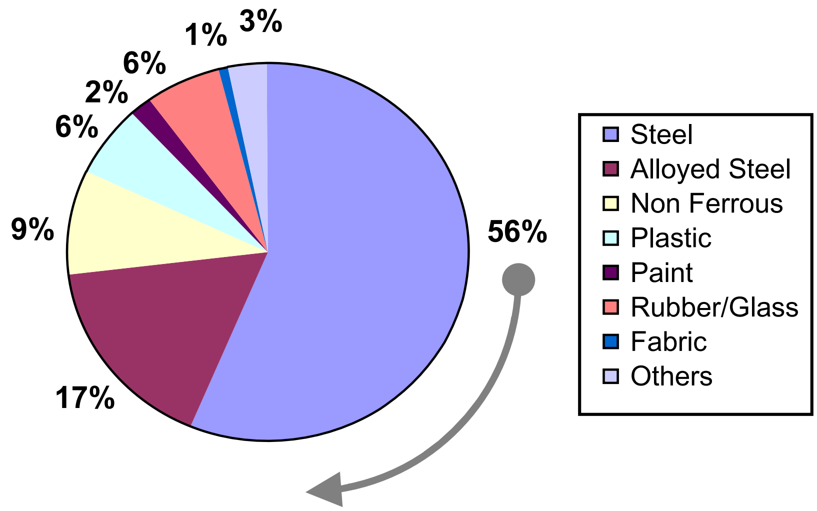


Figure 2. Utilization ratio of body materials.

Required properties of steel sheet

Steel sheet used to produce automobiles must possess the following properties:

- Strength
- Elongation
- Stamping formability
- Paintability

Steel used to reduce the weight of the body-in-white has increased strength and reduced gage in relation to the extra strength. Using such steel sheet for a large number of parts would provide a lighter body-in-white. It is commonly known, however, that typical high strength steel grades tend to exhibit reduced elongation when the strength increases as shown in Figure 3. This means that its stamping formability decreases resulting in a limited choice of applicable parts and, thus, opposing the goal of maximum weight reduction. With this in mind, target values for a developed material have been established as listed in Table II in the simultaneous pursuit of achieving higher strength and larger elongation.

The developed materials must exhibit good weldability, which is an essential aspect of automotive manufacturing. The paintability is also a major determinant of durability. Zinc coating of the steel sheet surface is a well-known technique for improving its corrosion resistance. However, the chemical composition of the steel may be unsuitable to be readily zinc coated and major discussions were conducted in this regard.

Developed material characteristics

Considering these property requirements, TRIP (transformation-induced plasticity) steel has been selected as a developed material. This steel grade is characterized by a fraction of retained, metastable austenite in the as-delivered state, which transforms into martensite when subjected to a forming process, such as stamping, thus exhibiting a high degree of elongation. Figure 4 shows a typical microstructure of the developed material. It was difficult to galvanneal TRIP steel using existing methods due to its composition, but since the latter has been optimized and the manufacturing conditions have been reviewed, galvannealing has become possible.

Table II. Target mechanical property for developed material.

Grade		TS (MPa)	YS (MPa)	EL (%)
780MPa	GA	780min.	400min.	19min.
	Bare	780min.	400min.	21min.
590MPa	GA	590min.	360min.	26min.
	Bare	590min.	350min	31min.

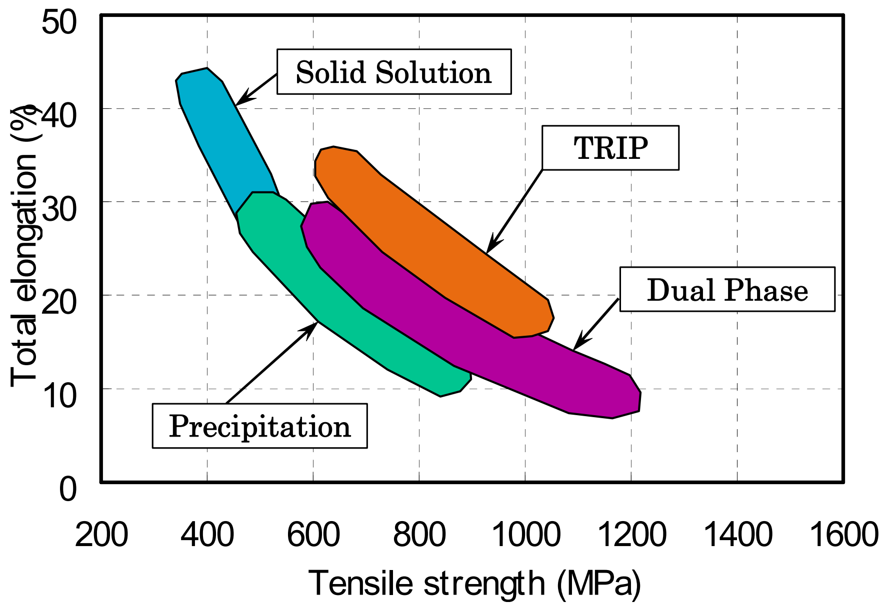


Figure 3. Typical mechanical property of steel sheet.

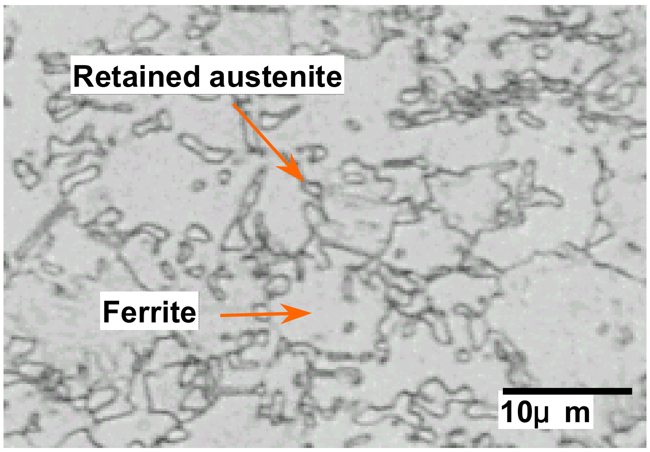


Figure 4. Microstructure of developed material.

Mechanical Properties of Developed Material

The developed material is available in two strength grades: 780 MPa and 590 MPa, respectively. Each grade comes either with or without galvannealing, adding up to a total line of four grades. Figure 5 shows the typical mechanical properties of the developed material.

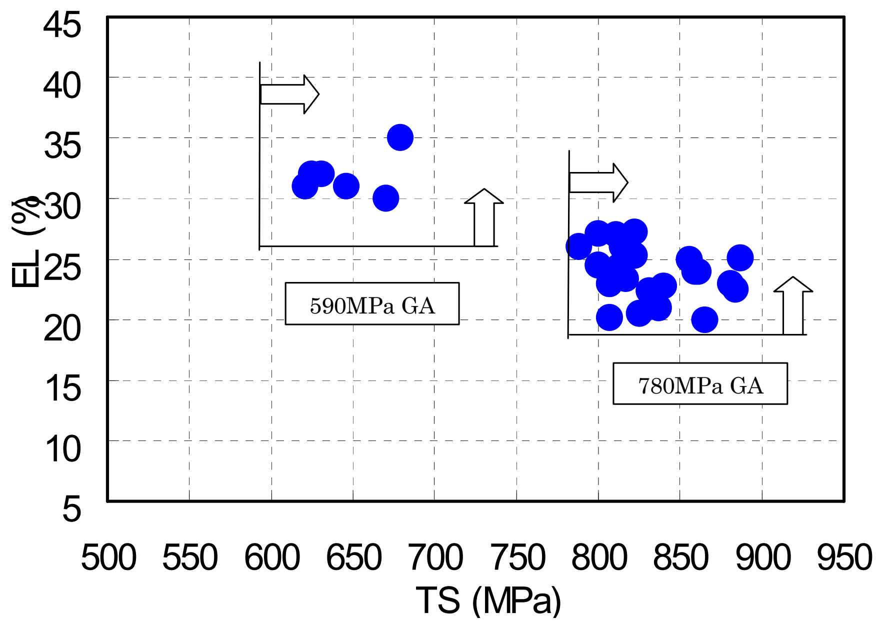


Figure 5. Typical mechanical properties of developed steels

Stamping Formability

The extended use of high strength steel within an automobile will further assist in the weight reduction of the body-in-white. To achieve this, the steel needs to have good stamping formability, which is also accepted as a key development goal because it could enable a wider scope of design features. Figure 6 is a Forming Limit Diagram (FLD) indicating the stamping formability of a steel grade and gage. As the diagram clearly shows, the developed material provides a stamping formability equivalent to a steel grade with a strength of one rank lower. This behavior suggests that the use of the developed material allows parts to be made of the same design as with steel having a strength of one rank lower. Consequently, steel sheets of one rank thinner gage can be used to make parts of the same strength.

Paintability

Automobiles should be designed to comply with various environments. Particularly in snowy districts the corrosion of automotive bodies caused by the use of snow-melting agents represents a major concern. For this purpose, automobiles are subjected to surface treatment (with a zinc phosphate) and coating (cathodic electro deposition) to establish full corrosion resistance. Figure 7 shows the conditions of the developed material versus the current material after zinc phosphate treatment. Apparently, the developed material exhibits the same surface conditions as the current material. Figure 8 shows the results of a corrosion test performed on the developed material versus the current material after cathodic electro deposition coating. Again, the developed material is seen to offer a corrosion resistance equivalent to the current material.

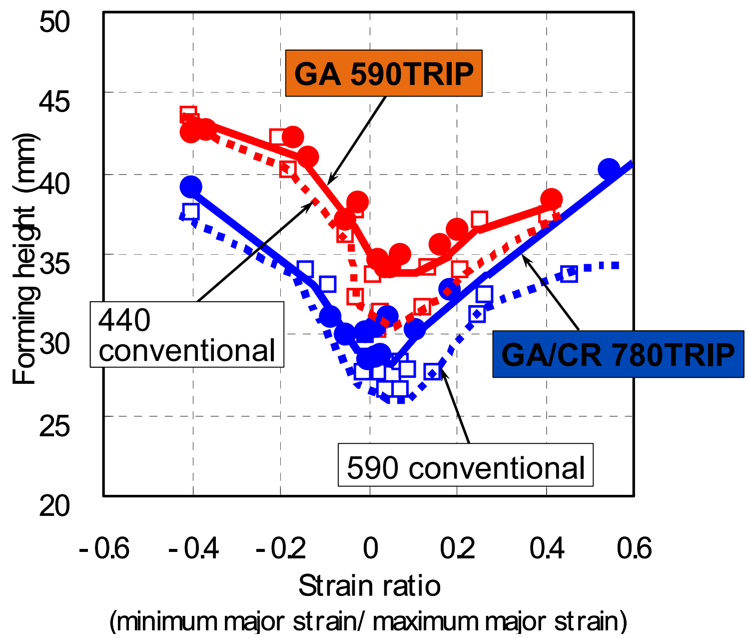
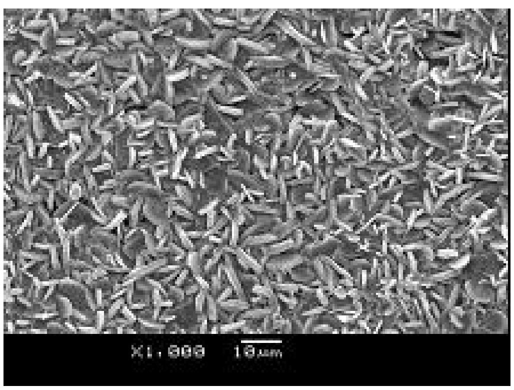


Figure 6. Forming limit diagram.



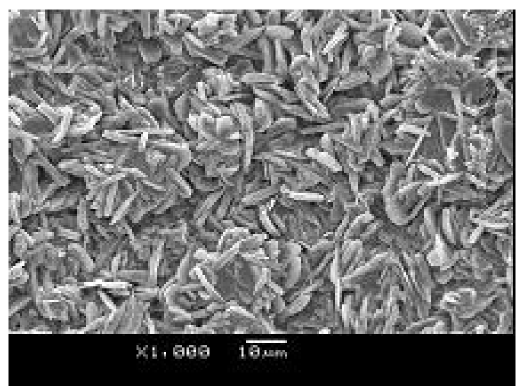


Figure 7. Morphology of zinc phosphate on current material (left) and developed material (right).

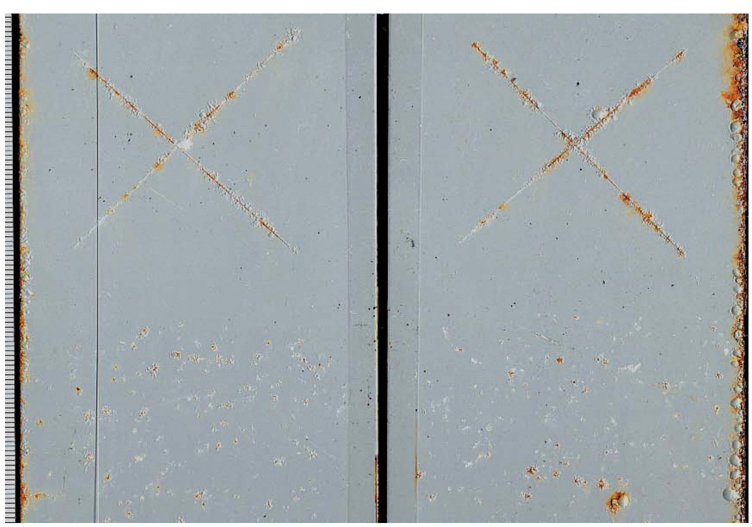


Figure 8. Results of corrosion test on current material (left) and developed material (right).

Conclusions

So far, Honda has developed a new variation of TRIP steel in cooperation with Japanese steel makers. The application of the developed material has been launched in the Honda 2004 models being manufactured in Japan. Figure 9 shows the typical effects of the use of the developed material. Use of the developed material is seen to offer a saving of about 10 kg in the body-in-white weight. Dedicated to extend the application of the developed materials to the manufacturing of automobiles at its overseas locations, Honda has been pursuing plans to develop similar materials in its key manufacturing countries of North America and Europe, jointly with local steel makers, and has prospects for the development of TRIP steel offering similar properties virtually in sight.

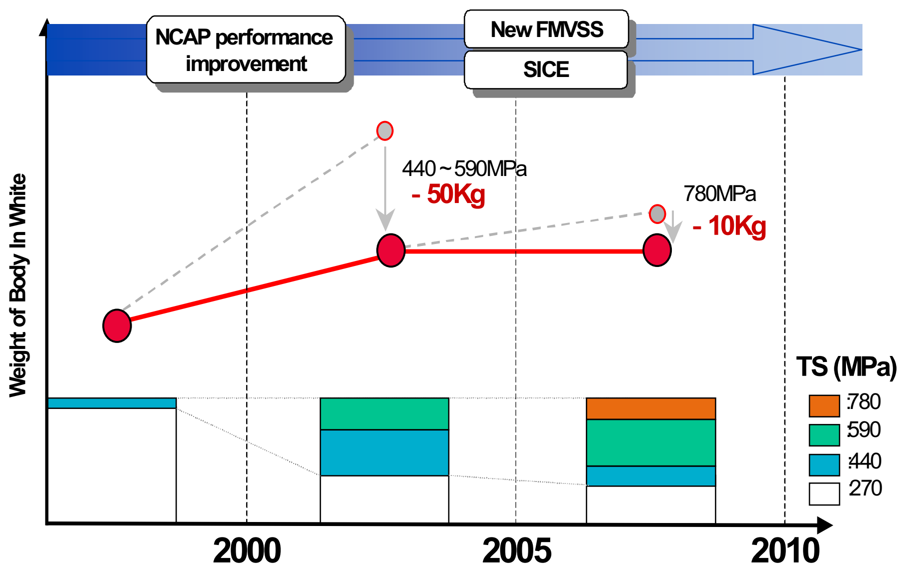


Figure 9. Weight reduction effects of developed materials

Efforts to make automobiles lighter are expected to further increase in response to concerns about environmental issues and demands to improve collision safety performance. Weight reduction is an elementary key technology to create automobiles providing excellent driving performance. While the development of design and production technologies that exploit a variety of materials is prerequisite to building lightweight bodies, it is hoped that further leaps in the development of steel materials will provide a major stimulation to the development of car weight reduction technologies.

References

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